The ωNN couplings derived from QCD sum rules

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Abstract

The light cone QCD sum rules are derived for the ωNN vector and tensor couplings simultaneously. The vacuum gluon field contribution is taken into account. Our results are $g_\omega = 18 \pm 8$, $\kappa_\omega = 0.8 \pm 0.4$.
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Recently the ρNN couplings were calculated in the framework of QCD sum rules using vector meson light cone wave functions [1]. Due to isospin symmetry the contribution from the vacuum gluon fields, which appears as the three particle rho meson wave functions, cancels exactly in the sum rules for the ρNN couplings. In this note we extend the same formalism to extract ωNN couplings in QCD. One big difference is that the vacuum gluon fields play an important role in the present case.

We omit the detailed derivation and present the final light cone sum rules and numerical results for ωNN couplings directly. Denote the ωNN vector coupling by g_ω and the tensor-vector coupling ratio by κ_ω. We have,

$$\begin{aligned}
\lambda_N^2\sqrt{2}g_\omega\frac{1+\kappa_\omega}{2}m_\omega^2 e^{-\frac{m_N^2}{M^2}} = \frac{1}{2\pi^2}e^{-\frac{u_0(1-u_0)m_\omega^2}{M^2}}\{-m_\omega g^v(u_0)M^6 f_2(\frac{s_0}{M^2})\\
-\frac{1}{3}f_\omega m_\omega\phi_\parallel(u_0)M^6 f_2(\frac{s_0}{M^2}) + 3f_\omega m_\omega^3 G_3(u_0)M^4 f_1(\frac{s_0}{M^2})\\
+f_\omega m_\omega^3 A(u_0)M^4 f_1(\frac{s_0}{M^2}) - \frac{1}{24}f_\omega m_\omega\langle g_s^2G^2\rangle g^v(u_0)M^2 f_0(\frac{s_0}{M^2})\\
+\frac{1}{2}f_{3\omega}^V[\frac{1}{2}I_0^v M^6 f_2(\frac{s_0}{M^2}) + m_\omega^2 I_2^v M^4 f_1(\frac{s_0}{M^2})]\\
+\frac{1}{2}f_{3\omega}^A[-\frac{1}{2}I_0^a M^6 f_2(\frac{s_0}{M^2}) + m_\omega^2 I_1^a M^4 f_1(\frac{s_0}{M^2})]\} \quad , \qquad (1)
\end{aligned}$$

$$\begin{aligned}
\lambda_N^2\sqrt{2}g_\omega e^{-\frac{m_N^2}{M^2}} = \frac{1}{2\pi^2}e^{-\frac{u_0(1-u_0)m_\omega^2}{M^2}}m_\omega\{-\frac{2}{3}f_\omega\phi_\parallel(u_0)M^4 f_1(\frac{s_0}{M^2})\\
+6f_\omega m_\omega^2 G_3(u_0)M^2 f_0(\frac{s_0}{M^2}) + 2f_\omega m_\omega^2 A(u_0)M^2 f_0(\frac{s_0}{M^2})
\end{aligned}$$

$$+f_{3\omega}^{V} m_\omega I_2^v M^2 f_0(\frac{s_0}{M^2}) + f_{3\omega}^{A} m_\omega I_1^a M^2 f_0(\frac{s_0}{M^2})\} \quad , \tag{2}$$

where $f_n(x) = 1 - e^{-x}\sum\limits_{k=0}^{n} \frac{x^k}{k!}$ is the factor used to subtract the continuum, s_0 is the continuum threshold, $\phi'_\omega(u_0) = \frac{d\phi_\omega(u)}{du}|_{u=u_0}$ etc. Since the initial and final states are the same, the sum rules are symmetric with the Borel parameters M_1^2 and M_2^2. It's reasonable to adopt $M_1^2 = M_2^2 = 2M^2$, i.e., $u_0 = \frac{1}{2}$. Such a symmetric choice enables a clean subtraction of the continuum and excited states contribution and leads to the above relatively simple expressions. We shall work in the physical limit $q^2 = m_\omega^2$.

We have defined

$$G_3(u) = \int_0^u dt \int_0^t ds C(s) \ , \tag{3}$$

The functions $I_i(u_0), i = 0, 1, 2, 3, 4$ are:

$$I_0^v = -2\int \mathcal{D}\underline{\alpha}\frac{\mathcal{V}(\alpha_i)}{\alpha_g^2}[\delta(\alpha_g+\alpha_3-u_0)-\delta(\alpha_3-u_0)]$$
$$+\int_0^1 d\alpha_g \int_0^{1-\alpha_g} d\alpha_3 \frac{1}{\alpha_g}\frac{d}{d\alpha_3}\mathcal{V}(1-\alpha_3-\alpha_g)[\delta(\alpha_g+\alpha_3-u_0)-\delta(\alpha_3-u_0)]$$
$$+\int_0^1 d\alpha_g \frac{\mathcal{V}(0,\alpha_g,1-\alpha_g)}{\alpha_g}\delta(1-u_0-\alpha_g) - \int_0^1 d\alpha_g \frac{\mathcal{V}(1-\alpha_g,\alpha_g,0)}{\alpha_g}\delta(\alpha_g-u_0) \quad , \tag{4}$$

$$I_0^a = +\int_0^1 d\alpha_g \frac{\mathcal{A}(0,\alpha_g,1-\alpha_g)}{\alpha_g}\delta(1-u_0-\alpha_g) + \int_0^1 d\alpha_g \frac{\mathcal{A}(1-\alpha_g,\alpha_g,0)}{\alpha_g}\delta(\alpha_g-u_0) \ , \tag{5}$$

$$I_1^F = \int_0^1 du \int \mathcal{D}\underline{\alpha}\mathcal{F}(\alpha_i)\delta(u\alpha_g+\alpha_3-u_0) \ , \tag{6}$$

$$I_2^F = \int_0^1 du \int \mathcal{D}\underline{\alpha}(1-2u)\mathcal{F}(\alpha_i)\delta(u\alpha_g+\alpha_3-u_0) \ , \tag{7}$$

where $\mathcal{F} = \mathcal{V}, \mathcal{A}$ respectively. The definitions of the other vector meson wave functions (VMWFs) can be found in [3].

At $u_0 = \frac{1}{2}$ we have [3] $g^v = 0.64$, $\phi_\parallel(u_0) = 1.1$, $G_3(u_0) = -0.13$, $A(u_0) = 2.18$, $I_0^v = 262.5$, $I_1^a = 2.04$, $I_2^v = 0.4375$, $I_0^a = 0$, $I_1^v = 0$, $I_2^a = 0$ at the scale $\mu = 1$GeV.

Numerically we have:

$$g_\omega(1+\kappa_\omega) = (45 \pm 9) \ , \tag{8}$$

$$g_\omega = (26 \pm 6) \ . \tag{9}$$

Dividing (1) by (2) we get a new stable sum rule for $1+\kappa_\omega$.

$$1+\kappa_\omega = (1.7 \pm 0.4) \ , \tag{10}$$

which corresponds to

$$\kappa_\omega = (0.7 \pm 0.4) \ . \tag{11}$$

The major uncertainty comes from the VMWFs since our final sum rules depend both on the value of WFs and their integrals at u_0. Especially, the sum rules (1) and (2) are sensitive to the variations of the values of VMWFs at $u_0 = \frac{1}{2}$. For example, we will get $g_\omega = (10 \pm 2)$ if we use the asymptotic form for the VMWFs. However, the ratio of these two sum rules is insensitive to the specific form of these VMWFs, $\kappa = 1.0 \pm 0.4$ for the asymptotic form of VMWFs. If we take into account the uncertainty in VMWFs by

treating the asymptotic form and the model wave functions as two opposite limits for the real VMWFs, we obtain:

$$g_\omega = (18 \pm 8) \ , \tag{12}$$

$$\kappa_\omega = (0.8 \pm 0.4) \ . \tag{13}$$

These results agree with a recent dispersion-theoretical analysis of the nucleon electromagnetic form factors [2], where vector meson nucleon couplings were extracted rather precisely:

$$g_\omega = (20.86 \pm 0.25) \ , \tag{14}$$

$$\kappa_\omega = (-0.16 \pm 0.01) \ . \tag{15}$$

It is interesting to notice that vacuum gluon fields play an important role in the vector meson nucleon interaction. Our result supports the large value for κ_ρ, g_ω. The naive relation $g_\omega = 3g_\rho$ does not hold any more. We want to emphasize that there are no free parameters in our calculation once the values of the VMWFs at the point $u_0 = \frac{1}{2}$ are determined, which is constrained by the QCD sum rule analysis of their moments to some extent [3].

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